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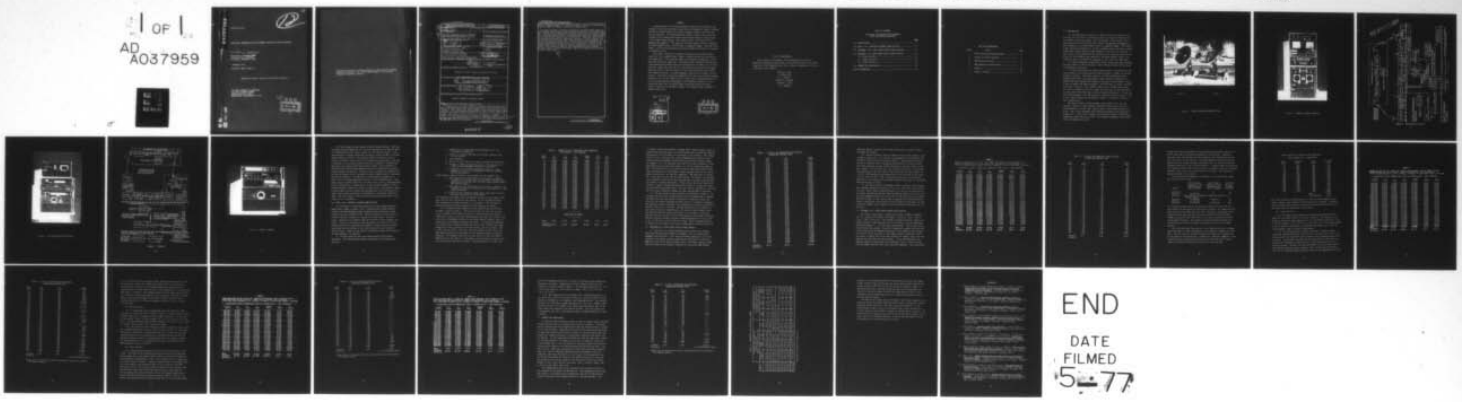

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TRAJECTORY DETERMINATION AND TELEMETRY RECEIVING SYSTEM EVALUATION

R. M. Fike s/c 404050

3 Electronics Lab~~oratory~~
1 Oklahoma State Uni~~versity~~
Stillwater, ~~Oklahoma~~ 74074

1 November 1976

Scientific Report Number 2

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A highly mobile, relatively inexpensive trajectory determination and telemetry receiving system has been previously developed to support sounding rocket launches at remote launch sites, where telemetry trackers and radar sets are not available. An S-band autotrack antenna system is used to provide telemetry data reception and azimuth and elevation angles to the position of the target being tracked. The tracking system is called Tratel for tracking and telemetry. The range to the target being tracked is provided by a PCM ranging system, called

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Tradat for trajectory data. The range from Tradat is used with the azimuth and elevation angles from Tratel to provide the trajectory data.

This report provides a trajectory evaluation of the Tratel/Tradat system for five sounding rocket flights, launched during three missions at two launch sites. The trajectory data was evaluated by comparing it with data from fixed site radar sets. Excellent quality telemetry data and autotrack azimuth and elevation data was received from all rockets in all three missions. Range data from the first two missions was excellent and range data from three of the five rockets in the third mission was good enough, with computer editing, to provide adequate trajectory data support for the mission. (The third mission was hampered by the loss of an airborne ranging receiver on one of the rockets prior to launch, and by ranging dropouts due to an improper modulation adjustment to the ranging transmitter.) This evaluation shows that the Tratel/Tradat system can provide excellent quality trajectory and telemetry support for sounding rockets launched at remote launch sites.

SUMMARY

A highly mobile, relatively inexpensive trajectory determination and telemetry receiving system has been previously developed to support sounding launches at remote launch sites, where telemetry trackers and radar sets are not available. An S-band autotrack antenna system is used to provide telemetry data reception and azimuth and elevation angles to the position of the target being tracked. The tracking system is called Tratel for tracking and telemetry. The range to the target being tracked is provided by a PCM ranging system, called Tradat for trajectory data. The range from Tradat is used with the azimuth and elevation angles from Tratel to provide the trajectory data.

This report provides a trajectory evaluation of the Tratel/Tradat system for five sounding rocket flights, launched during three missions at two launch sites. The trajectory data was evaluated by comparing it with data from fixed site radar sets. Excellent quality telemetry data and auto-track azimuth and elevation data was received from all rockets in all three missions. Range data from the first two missions was excellent and range data from three of the five rockets in the third mission was good enough, with computer editing, to provide adequate trajectory data support for the mission. (The third mission was hampered by the loss of an airborne ranging receiver on one of the rockets prior to launch, and by ranging dropouts due to an improper modulation adjustment to the ranging transmitter.) This evaluation shows that the Tratel/Tradat system can provide excellent quality trajectory and telemetry support for sounding rockets launched at remote launch sites.

LIST OF CONTRIBUTORS

The following staff members of the Oklahoma State University Electronics Laboratory contributed to the work described in this report. (Names are listed alphabetically, not in order of importance of the contribution to this effort):

Richard F. Buck
R. Michael Fike
L. O. Schmitt
Rosalee I. Stafford
Barbara L. Tyler
J. R. Waughtal

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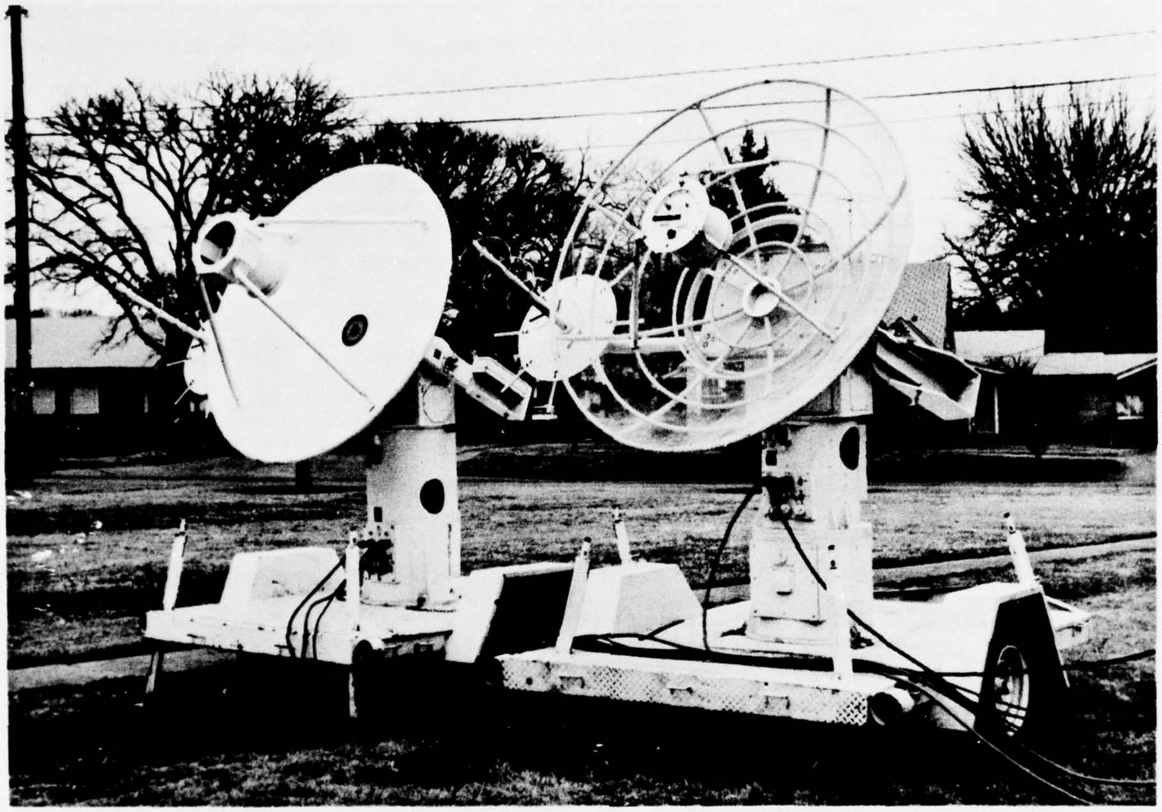
1.0 INTRODUCTION

1.1 The Oklahoma State University (OSU), Electronics Laboratory has developed a highly mobile, relatively inexpensive trajectory determination and telemetry receiving system. The Tratel/Tradat system consists of an autotrack antenna system called Tratel (short for tracking and telemetry) and a ranging system called Tradat (short for trajectory data). The Tratel/Tradat system was developed for use with sounding rockets launched at remote launch sites, where radar sets and telemetry trackers are not available. This report is an evaluation of the accuracy of the trajectory data and the quality of the telemetry data acquired by the Tratel/Tradat system. The trajectory data is evaluated by comparing it with fixed-site radar data.

1.2 Several different ranging and tracking systems have been developed and field tested by OSU in the past. These systems are described in detail in References 1 through 10.

1.3 OSU has developed two Tratel systems (Tratel I and Tratel II) and three currently used trajectory data systems (Tradat I, Tradat II, and PCM Trajectory System). The Tratel system is a trailer-mounted autotrack antenna system used to provide telemetry data reception, together with azimuth (Az) and elevation (El) angles to the source of the signal. Tratel I and II trackers are shown in Figure 1, and the Tratel II control consoles are shown in Figure 2. The trajectory data system provides slant range data and also formats the Az, El, range, and IRIG time in a PCM code which is synchronized with IRIG time to better than one millisecond. A block diagram and photograph of the PCM trajectory system are shown in Figures 3 and 4, and a block diagram and photograph of Tradat I are shown in Figures 5 and 6 respectively.

The Tratel S-band autotrack antenna system consists of a six foot parabolic reflector, single channel monopulse RF feed, elevation-over-azimuth pedestal, trailer, 200' control cables, and portable control consoles. Most of the components were originally purchased from Scientific-Atlanta, Inc. The Az and El angles are provided by synchro to BCD digital converters, which read out to 0.01°. For detailed information about Tratel refer to References 9 and 10.



Tratel II　　　　　　　　　　　　　　Tratel I

Figure 1. TRATEL AUTOTRACK ANTENNA SYSTEMS

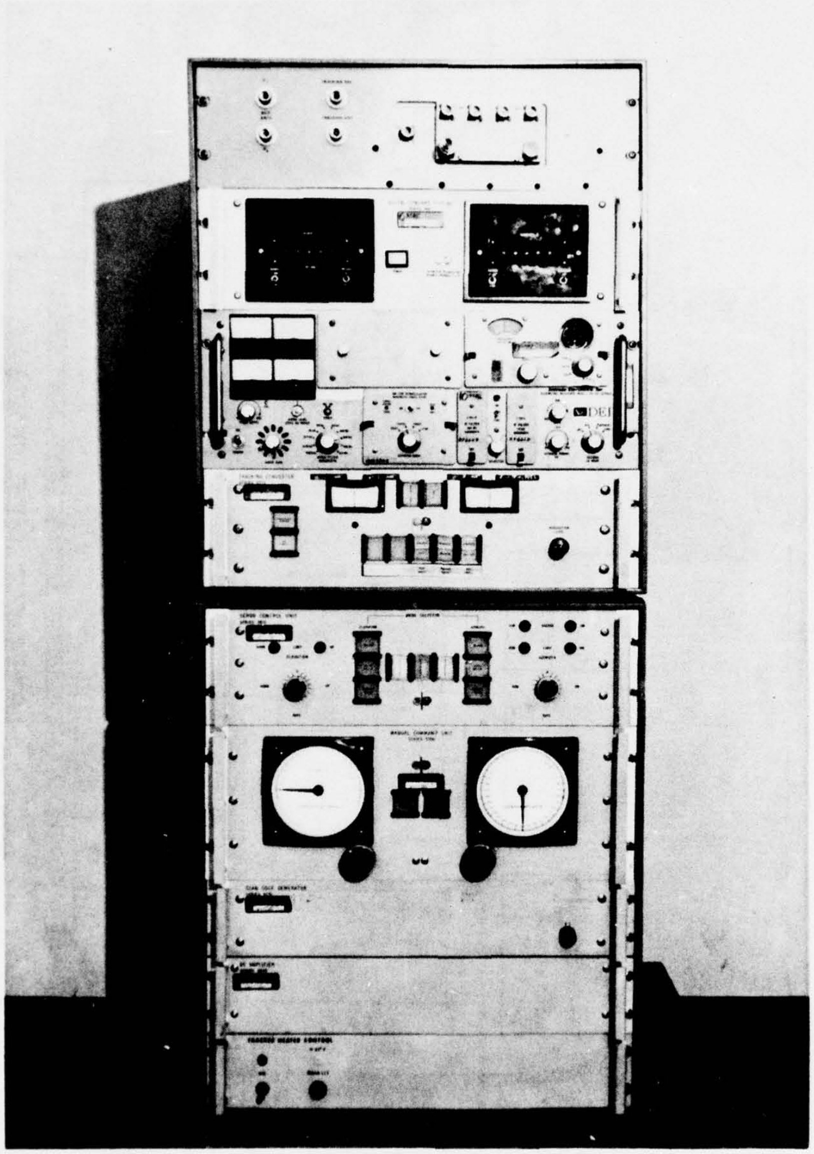


Figure 2. TRATEL II CONTROL CONSOLES

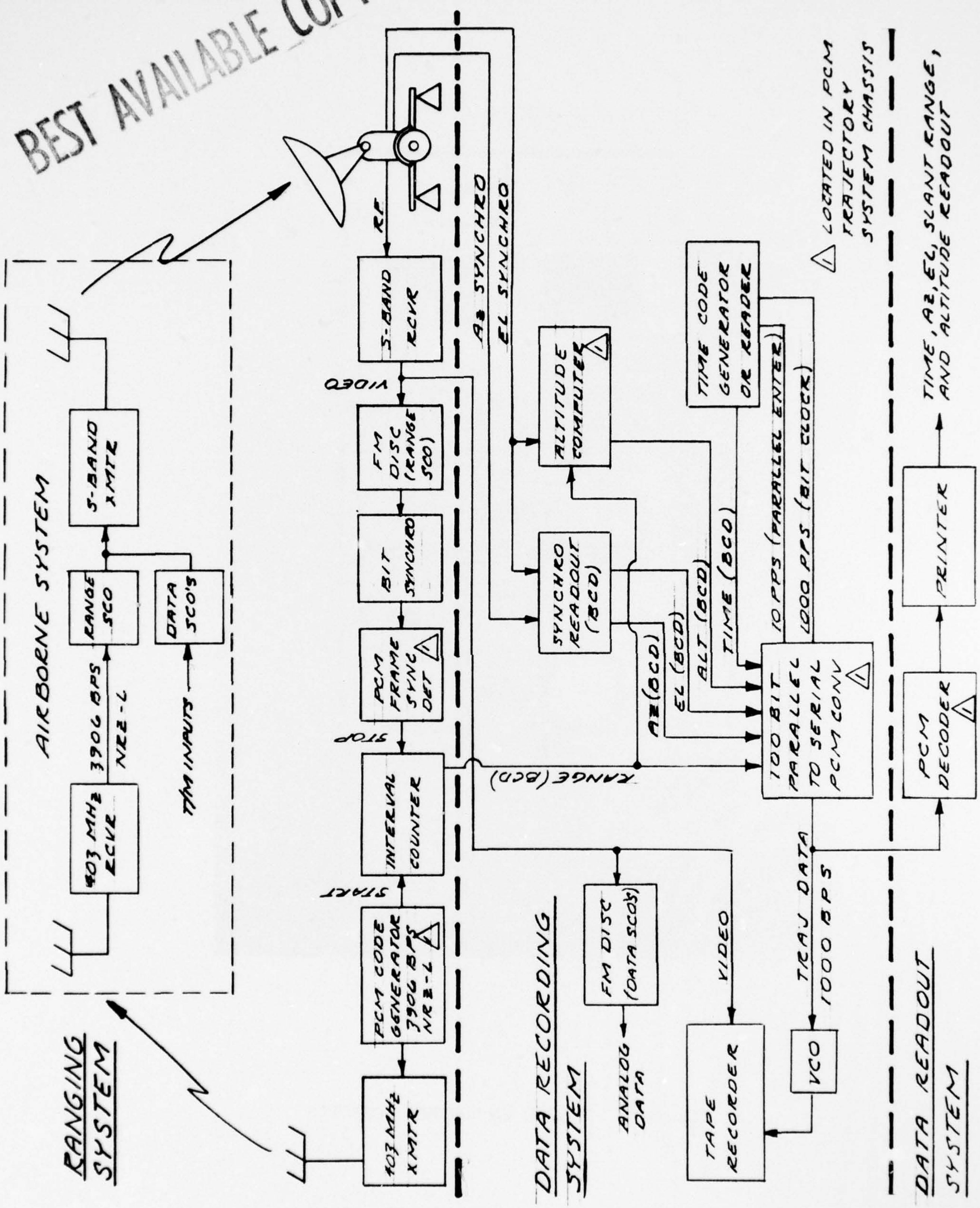


Figure 3. PCM Trajectory System

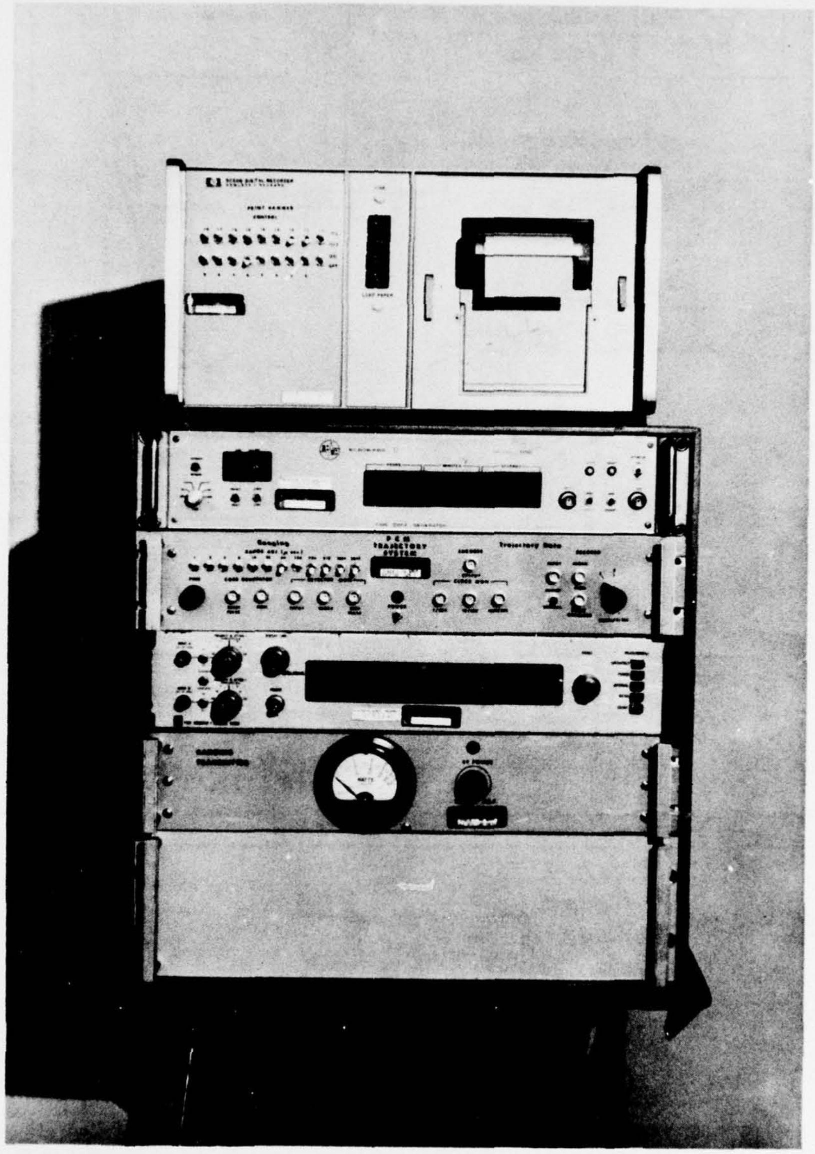


Figure 4. PCM TRAJECTORY SYSTEM CONSOLE

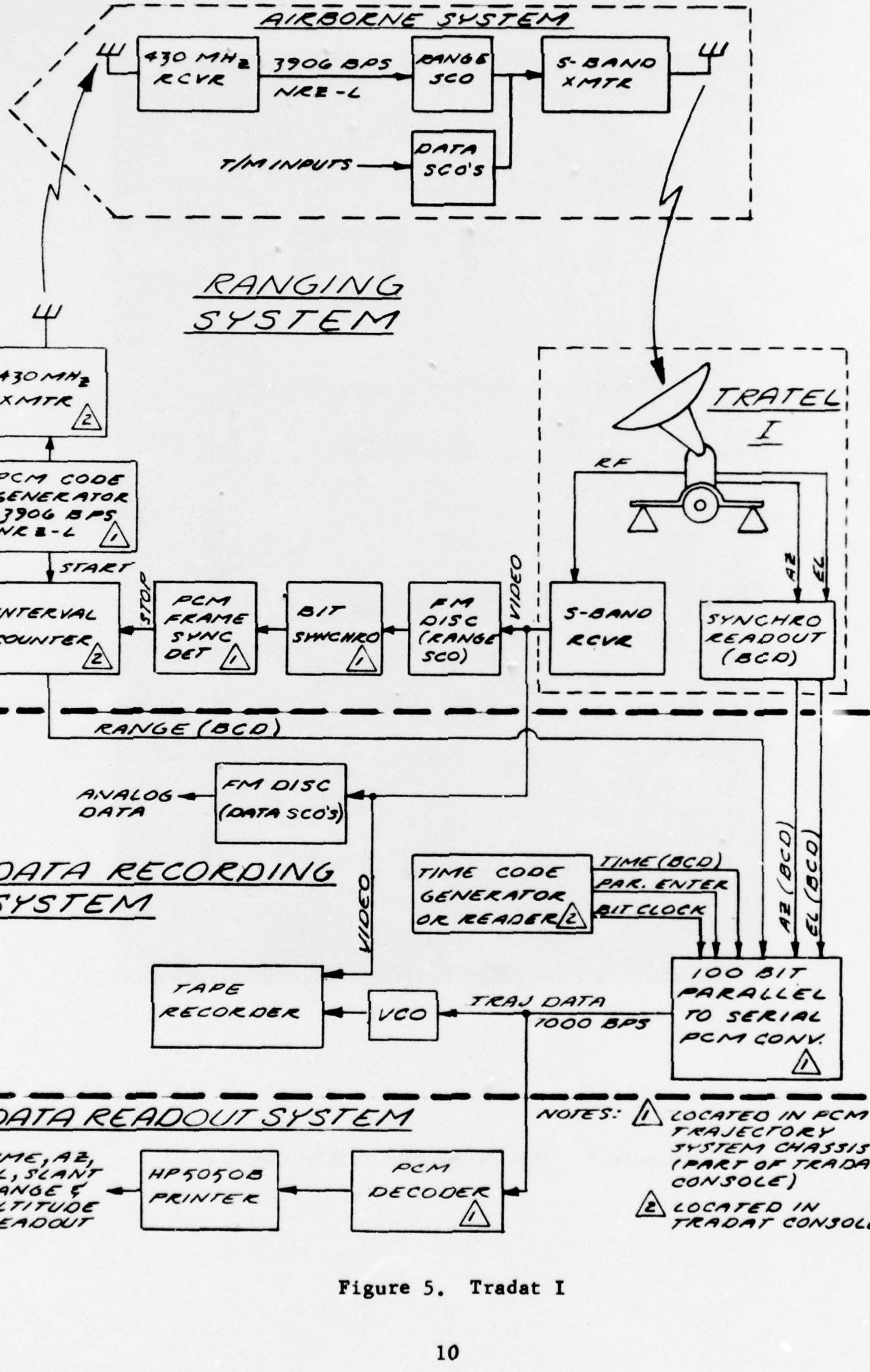


Figure 5. Tradat I

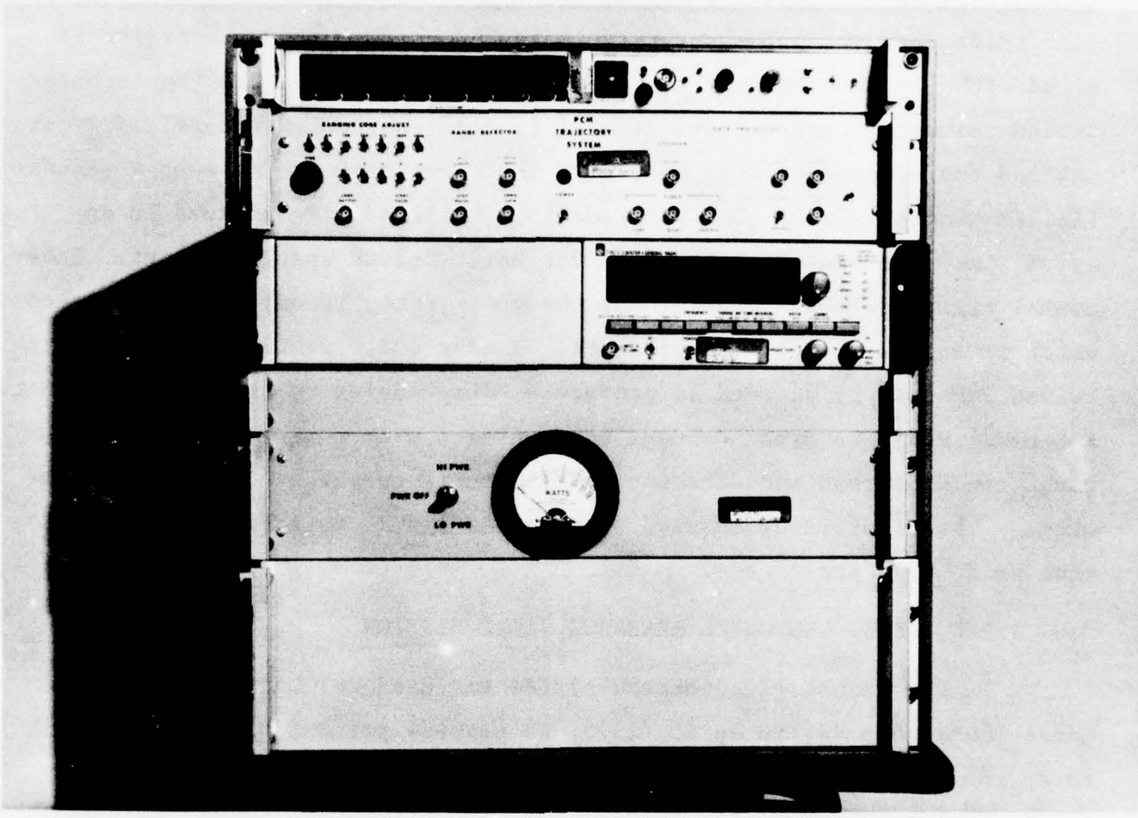


Figure 6. TRADAT I CONSOLE

All three ranging systems operate using the same technique. Deriving the range involves generation of a crystal-controlled 14-bit PCM code which is synchronized with the "start" pulse to a time interval counter. This code modulates a ranging transmitter (currently, either 403 MHz or 430 MHz) which transmits the code to the airborne receiver by means of a helix antenna, attached to and pointed by the S-band autotrack antenna. The code is detected in the airborne receiver and used to modulate a standard IRIG subcarrier (any channel above band 14 may be used). This subcarrier is mixed with the data-bearing subcarriers and used to modulate the airborne S-band telemetry transmitter. Tratel is used to receive the telemetry signal and the ranging code is retrieved from the telemetry data by a standard IRIG FM discriminator. The PCM code is stabilized and reshaped in an Aacom, Inc. bit synchronizer which was built to OSU specifications. Under normal signal strength conditions, the code jitter is only $\pm$ 200 nanoseconds, which is equivalent to a range jitter of only $\pm$ 0.030 kilometers. The received PCM code is decoded to produce a "stop" pulse to the interval counter. A General Radio interval counter was modified with a new time base so the range could be read out directly in kilometers to the nearest 0.010 kilometer. The slant range is used with the Az and El data from Tratel to provide an X, Y, Z trajectory.

2.0 APRIL, 1975, CHURCHILL RESEARCH RANGE MISSION

2.1 The Tratel II autotrack system was used at Churchill Research Range (CRR), Canada, in April, 1975, to provide prime S-band telemetry reception for Nike-Tomahawk rocket A10.302-3 because fixed-site S-band trackers were not available at CRR. The PCM trajectory system was used to provide trajectory coverage as a backup for the CRR radar. Excellent quality trajectory and telemetry data were received by OSU throughout the flight. This was a particularly good opportunity to evaluate the Tratel system because of the remoteness of Churchill, Canada, the Arctic winter conditions, and the pressure on the crew of being the prime S-band receiving system. These are the types of conditions in which the Tratel system was designed to be operated.

2.2 The OSU trajectory data was reduced using the OSU computer facilities. The OSU-developed computer program has the following capabilities:

1. Converts Az, El, range spherical coordinates to X, Y, Z rectangular coordinates.
2. Ability to translate OSU data to any other location, such as the launcher.
3. Data smoothing.
4. Ability to shift the data in time to compare with radar data.
5. Editing to replace missing data points. The equations include altitude-dependent gravity and drag effects.
6. An equation for the azimuth boresight correction. (See Appendix A, Section 5.0 of Reference 9 for this equation and its derivation.)

Three separate computer printouts are provided for each computer run:

1. OSU trajectory data translated to the launcher, including: universal time; launch time; X-Y-Z position, velocity, and acceleration; mean sea level altitude; range; azimuth angle; and elevation angle.
2. OSU trajectory data referenced to the tracker, including: unsmoothed; smoothed; and unsmoothed minus smoothed Az, El, and range (residuals).
3. Trajectory data comparison (radar minus OSU tracker) of X-Y-Z position, range, and Az and El angles.

Ten trajectory data points are recorded every second, but the computer uses and prints out only one data set per second. In the following analyses, data comparisons are made only every 5 or 10 seconds. This provides an adequate sampling for proper analysis without being too voluminous.

2.3 A trajectory data comparison of the smoothed OSU and CRR radar #2 radar is given in Table 1. The positive X-axis is East, the positive Y-axis is North, and the positive Z-axis is altitude above the launcher. A comparison is given to only 140 seconds because the radar lost track at that time (due to transponder failure, or some other reason); however, OSU trajectory data was received throughout the flight. The trajectory comparison is excellent with a maximum altitude deviation of only 0.091 Km and a mean deviation of 0.032 $\pm$ .039 Km in altitude, 0.034 $\pm$ .030 Km in range, 1.02° $\pm$ $.49^{\circ}$ in Az and $.02^{\circ}$ $\pm$ $.07^{\circ}$ in El. The first number in each case is the mean deviation and the second number is the standard deviation, using N-1 weighting. For example, using the altitude, there is a bias of 0.032 Km between the two and there is a one sigma or 68.3% probability that all the data lie within $\pm$ .039 Km of the mean. The mean deviation of 1.02° in Az

TABLE 1. ROCKET A10.302-3 TRAJECTORY DATA COMPARISON
(CRR RADAR #2 - OSU TRACKER)

Time (Sec)	X (KM)	Y (KM)	Z (KM)	Range (KM)	Az (Deg)	El (Deg)
10	0.033	0.015	0.060	0.060	-1.61	0.05
15	0.040	0.020	0.070	0.070	-1.53	0.02
20	0.107	0.033	-0.054	-0.046	-2.95	-0.27
25	0.084	0.041	-0.025	-0.020	-1.88	-0.10
30	0.061	0.044	0.091	0.091	-1.02	0.00
35	0.088	0.067	0.018	0.021	-1.07	-0.03
40	0.141	0.085	0.066	0.073	-1.22	-0.05
45	0.123	0.092	-0.024	-0.019	-0.95	-0.05
50	0.176	0.041	0.032	0.049	-0.79	-0.10
55	0.162	0.118	0.072	0.079	-0.92	-0.03
60	0.142	0.151	0.022	0.024	-0.87	-0.01
65	0.194	0.200	0.025	0.029	-1.05	-0.01
70	0.217	0.177	0.044	0.053	-0.94	-0.04
75	0.234	0.191	0.036	0.046	-0.93	-0.04
80	0.256	0.193	0.026	0.040	-0.90	-0.04
85	0.268	0.209	0.012	0.026	-0.89	-0.04
90	0.258	0.225	-0.009	0.002	-0.84	-0.03
95	0.275	0.220	-0.006	0.009	-0.80	-0.04
100	0.268	0.245	0.022	0.032	-0.78	-0.02
105	0.229	0.289	0.045	0.043	-0.75	0.00
110	0.197	0.336	0.039	0.028	-0.74	0.02
115	0.178	0.366	0.060	0.041	-0.72	0.04
120	0.148	0.400	0.074	0.046	-0.69	0.05
125	0.126	0.439	0.074	0.037	-0.69	0.06
130	0.154	0.472	0.074	0.037	-0.73	0.06
135	0.208	0.449	0.072	0.046	-0.72	0.04
140	0.505	0.201	-0.042	0.015	-0.69	-0.09
RADAR LOSS OF SIGNAL						
Mean	0.180	0.197	0.032	0.034	1.02	0.02
Standard Deviation	±0.096	±0.140	±0.039	±0.030	±0.49	±0.07

is somewhat larger than expected, although fairly large Az angle biases are normal during the first part of a rocket flight when the elevation angle is high because of the proximity of the tracker to the launcher. This larger Az bias is due to the fact that any Az boresight error or any Az servo system electrical imbalance is multiplied by the secant of the El angle. For example, a 0.1° Az boresight error and 0.1° Az servo imbalance in the same direction would give an Az offset of 1.15° at an elevation angle of 80°. This source of error is true for both the radar and the OSU tracker. Other possibilities for this offset include improper Tratel set-up and improper translation of the data for comparison. The radar data is suspect due to the radar loss of track at T+140 seconds. Fortunately, the Az angle is of secondary importance for most missions and is normally only required for recovery or impact information. The Az data is much more accurate for recovery or impact information because the El angle is low and the secant error multiplier approaches unity. The most important parameter is altitude and the altitude comparison between the radar and OSU data is excellent.

2.4 The OSU trajectory data residuals are presented in Table 2. The residuals are merely the unsmoothed data minus the smoothed data. Whereas the comparison with radar gives an indication of absolute accuracy and shows any data biases (assuming the radar really is an absolute standard), the residuals provide a measure of the smoothness of the data or conversely how much jitter was in the data. The mean deviation of the residuals is zero since the data is smoothed about its mean in a least squares sense. The standard deviation figures mean there is a one sigma or 68.3% probability that all the data lie within the bounds of one standard deviation. The data indicate a smooth track with standard deviations of only $\pm 0.13^{\circ}$ in Az, $\pm 0.05^{\circ}$ in El, and $\pm$ 0.065 Km in range. The Az standard deviation is larger than El because of the reasons mentioned in the previous section.

3.0 SEPTEMBER, 1975, WHITE SANDS MISSILE RANGE MISSION

3.1 The Tratel II system and PCM Trajectory System were tested at White Sands Missile Range (WSMR) in September, 1975, by tracking Nike-Tomahawk rocket A10.304-1. This was an excellent opportunity to test the accuracy of the Tratel system by comparing the OSU trajectory data with WSMR fixed site FPS-16 radar trajectory data. The Tratel system provided back-up trajectory and telemetry reception for the normal WSMR support.

TABLE 2. A10.302-3 OSU TRAJECTORY DATA RESIDUALS
(UNSMOOTHED-SMOOTHED DATA)

Time (Sec)	Az (Deg)	El (Deg)	Range (Km)
10	-0.04	-0.04	-0.046
20	-0.03	-0.01	-0.076
30	0.03	0.01	0.240
40	0.01	0.00	-0.076
50	0.00	-0.01	0.000
60	-0.23	-0.12	0.043
70	-0.10	-0.03	0.133
80	-0.14	-0.01	-0.080
90	-0.22	0.02	-0.027
100	-0.02	-0.05	0.035
110	-0.36	-0.01	0.088
120	-0.17	0.04	-0.062
130	-0.34	0.04	0.006
140	0.03	0.02	0.059
150	0.12	0.03	0.058
160	0.26	0.00	-0.092
170	0.45	0.01	-0.018
180	0.17	-0.01	0.040
190	0.06	0.00	0.030
200	0.05	-0.01	0.003
210	0.53	0.04	-0.010
220	0.27	0.00	0.026
230	0.07	-0.01	-0.036
240	-0.09	-0.05	-0.056
250	0.02	-0.05	-0.020
260	-0.07	-0.08	-0.062
270	-0.06	0.00	-0.100
280	-0.00	0.05	0.002
290	0.08	0.08	0.017
300	0.15	0.06	-0.006
310	0.24	0.00	-0.014
320	0.45	0.05	-0.037
330	0.05	-0.01	0.014
340	-0.03	-0.03	0.063
350	-0.09	0.02	-0.004
360	-0.34	0.18	-0.034
370	-0.04	0.10	-0.031
380	0.07	0.00	-0.024
390	0.09	0.00	0.141
400	0.02	-0.01	0.045
410	0.02	0.00	0.009
420	0.02	-0.01	-0.053
430	0.01	0.00	0.033
440	0.02	0.00	0.032
Standard Deviation	±0.13	±0.05	±0.065

Excellent quality trajectory and telemetry data were received by Tratel throughout the flight.

3.2 The OSU trajectory data was reduced using the OSU computer as described in Section 2.2. A trajectory data comparison of the smoothed OSU and FPS-16 radar #113 data is given in Table 3. The trajectory data comparison is excellent with a maximum altitude deviation of only 0.164 Km and a mean deviation of only -0.012 $\pm$ 0.072 Km in altitude, 0.045 $\pm$ 0.017 Km in range, $-0.17^{\circ} \pm 0.21^{\circ}$ in Az, and $-0.04^{\circ} \pm 0.05^{\circ}$ in El. The Az angle mean deviation for the first half of the flight (through 220 seconds) is $-0.31^{\circ} \pm 0.20^{\circ}$ whereas the mean deviation for the last half of the flight is only $-0.03^{\circ} \pm 0.08^{\circ}$. This illustrates how any small Az biases are amplified by the secant of the El angle during the first part of the flight when the El angle is large.

3.3 The trajectory data residuals in Table 4 indicate a smooth track with standard deviations of only $\pm .17^{\circ}$ in Az, $\pm .03^{\circ}$ in El, and $\pm$ .028 Km in range. The Az angle standard deviation is $\pm .20^{\circ}$ for the first half of the flight (through 220 seconds) when the elevation angle is high, but the Az angle standard deviation is only $\pm .04^{\circ}$ for the last half of the flight when the El angle is low. Again, this is because the Az autotrack error signal is multiplied by the secant of the El angle; and therefore, any perturbations onthe Az error signal are also multiplied by the secant of the El angle.

4.0 DECEMBER, 1975, WHITE SANDS MISSILE RANGE MISSION

The Tratel II and Tradat I systems were tested at WSMR in December, 1975, by tracking six Astrobee "D" rockets: A30.311-8, .311-5, .311-7, .413-5, .205-7, and .413-4. The telemetry reception and Az-El angles provided by Tratel II were excellent on all the rockets, but the range data provided by Tradat was poor with many range dropouts. Post mission evaluation revealed the problem. Relatively inexpensive ranging receivers with a relatively narrow RF bandwidth were used in the rockets on this mission. On the first flight (A30.311-8), the ranging receiver apparently failed just prior to launch and on the other missions the ranging signal from the receiver was very weak with many dropouts. It was discovered that the ranging transmitter modulation was inadvertently set at a level too high for the ranging receivers with their narrow RF bandwidth. This drastically

TABLE 3

VEHICLE A10.304-1, 18 SEPT 75, WSMR, NEW MEXICO, LCH-1FROM L-479
DATA ORIGIN LAT 32 25 0.41, LONG 106 19 30.99, ALT 1.233 KM
T-0: 19H 47M 00.191S U.T.; X-EAST, Y-NORTH, Z-ALTITUDE ABOVE LAUNCHER

TRAJECTORY DATA COMPARISON (FPS-16 RADAR #113 - OSU TRACKER)

T-LNCH (SEC)	X (KM)	Y (KM)	Z (KM)	RANGE (KM)	AZ (DEG)	EL (DEG)
49.809	-0.103	0.004	0.043	0.048	-0.51	-0.02
59.809	-0.101	0.010	0.037	0.044	-0.41	-0.03
69.809	-0.064	0.019	0.036	0.044	-0.19	-0.02
79.809	-0.011	0.020	0.040	0.044	-0.01	-0.01
89.809	0.010	0.018	0.043	0.045	0.04	-0.00
99.809	0.008	0.020	0.046	0.048	0.03	-0.00
109.809	-0.111	0.084	0.019	0.048	-0.16	-0.05
119.809	-0.108	0.007	0.043	0.052	-0.18	-0.01
129.809	-0.178	-0.013	0.042	0.052	-0.28	-0.01
139.809	-0.253	-0.031	0.038	0.050	-0.37	-0.01
149.809	-0.330	-0.035	0.029	0.048	-0.45	-0.02
159.809	-0.528	0.076	-0.034	0.045	-0.62	-0.10
169.809	-0.437	-0.010	0.004	0.046	-0.50	-0.05
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199.809	-0.418	0.071	-0.031	0.052	-0.38	-0.08
209.809	-0.388	0.120	-0.045	0.061	-0.32	-0.10
219.809	-0.332	0.143	-0.047	0.069	-0.25	-0.10
229.809	-0.279	0.162	-0.050	0.075	-0.19	-0.10
239.809	-0.218	0.160	-0.046	0.077	-0.13	-0.09
249.809	-0.222	0.198	-0.087	0.075	-0.12	-0.12
259.809	-0.176	0.170	-0.084	0.065	-0.09	-0.10
269.809	-0.127	0.116	-0.072	0.044	-0.06	-0.08
279.809	-0.093	0.108	-0.089	0.031	-0.04	-0.08
289.809	-0.053	0.115	-0.104	0.030	-0.01	-0.08
299.809	-0.088	0.096	-0.127	0.026	-0.04	-0.09
309.809	-0.166	0.040	-0.145	0.011	-0.09	-0.09
319.809	-0.077	0.050	-0.041	0.052	-0.04	-0.04
329.809	-0.019	0.036	-0.095	0.019	-0.00	-0.06
339.809	-0.072	0.065	-0.001	0.084	-0.04	-0.00
349.809	0.135	0.072	0.143	0.041	0.09	0.08
359.809	0.076	0.068	-0.135	0.031	0.05	-0.08
369.809	-0.005	0.036	0.038	0.038	0.00	0.02
379.809	0.129	0.070	0.048	0.032	0.08	0.03
389.809	0.198	0.073	0.028	0.013	0.12	0.02
399.809	0.040	0.018	0.164	0.012	0.03	0.10
Mean:	**-0.146**	**0.063**	**-0.012**	**0.045**	**-0.17**	**-0.04**
Standard:	**±0.182**	**±0.062**	**±0.072**	**±0.017**	**±0.21**	**±0.05**

TABLE 4. A10.304-1 OSU TRAJECTORY DATA RESIDUALS
(UNSMOOTHED-SMOOTHED DATA)

Time (Sec)	Az (Deg)	El (Deg)	Range (Km)
50	-.15	-.04	.004
60	-.80	-.01	.013
70	-.30	-.01	.001
80	-.23	.00	-.011
90	-.25	-.01	-.022
100	-.18	.01	.003
110	.25	-.02	.013
120	.27	.03	.002
130	.02	.00	.009
140	-.05	.03	.003
150	-.10	-.02	.008
160	-.13	.01	.004
170	-.10	.02	.009
180	.59	.01	.018
190	.06	.05	.005
200	-.07	-.02	.026
210	-.07	.00	.015
220	.02	-.02	.016
230	.01	-.02	.041
240	.02	-.03	.043
250	-.01	-.04	.037
260	-.02	-.01	.019
270	.02	-.02	-.024
280	-.02	-.01	.018
290	.00	.00	.004
300	.00	.00	.009
310	.13	-.01	.131
320	-.09	.05	.058
330	-.06	-.03	-.021
340	-.01	.00	.035
350	-.14	-.02	-.003
360	.00	.00	-.007
370	.04	.04	-.014
380	-.05	-.08	.009
390	-.02	.13	.015
400	-.09	-.02	-.024
Standard Deviation	±.17	±.03	±.028

reduced the receiving threshold of the receiver because a major portion of the RF energy was outside the RF bandwidth of the receiver. Unknown to the field crew, the modulation of the transmitter was increased during lab tests just prior to this mission. The higher modulation would have been no problem with the ranging receivers used previously, but with the narrow RF bandwidth receivers, it was a serious problem. A simpler means of monitoring the transmitter modulation in the field has been added to avoid this potential problem in the future. Also, more care will be given to the selection of ranging receivers in the future.

The following table summarizes the amount of time the PCM data range was received on each rocket:

Rocket	Time of Range Reception in Sec (Maximum Range After Liftoff)	Time of Range Reception in Sec (Maximum Range Prior to Impact)	Total Time of Range Reception (Seconds)
A30.311-8	0	0	0
A30.311-5	20 (15 Km)	0	20
A30.311-7	Range received throughout flight with dropouts in middle portion.		
A30.413-5	97 (100 Km)	71 (85 Km)	174
A30.205-7	58 (65 Km)	0	58
A30.413-4	172 (134 Km)	48 (100 Km)	220

All trajectory comparisons in the following sections for this mission include edited portions where the range data is missing. No comparisons were made with data from rocket A30.311-8 since there was no range data, and no comparisons were made with data from rocket A30.311-5 since the range reaches a maximum of only 15 Km, which is too low to provide an accurate extrapolated trajectory. The computer edited trajectories provided are accurate enough to meet the mission requirements in spite of the range dropouts.

The radar data from this mission is less than desirable as a standard since there were no radar transponders in the rockets to enhance the radar data. The skin track of the small Astrobee "D" rockets (6" diameter) was not as smooth as was desired for a standard for trajectory comparison. The following table, comparing altitude data from rocket A30.413-5 from two radars, illustrates the amount of deviation in the radar data:

Rocket A30.413-5 Trajectory Data Comparison

(FPS-16 Radar #114 - Radar #124)

Time (Sec)	Altitude (Km)	Time (Sec)	Altitude (Km)
40	.048	190	-.023
50	-.083	200	-.323
60	.031	210	-.128
70	-.214	220	.028
80	.052	230	-.053
90	-.218	240	-.093
100	-.366	250	-.130
110	.068	260	-.016
120	-.058	270	.011
130	-.048	280	-.156
140	.017	290	-.022
150	.005	300	-.041
160	-.256	310	-.017
170	-.040	320	-.010
180	-.170	330	-.015
		Mean:	-.076
		Std. Deviation:	$\pm$.110

This table indicates a mean deviation of -.076 $\pm$ .110 Km between the two radars, which is more deviation than desirable for a standard. The radar data from other rocket flights on this mission varied from much better to much worse than the sample data in this table.

4.1 Rocket A30.311-7

4.1.1 A trajectory data comparison of the smoothed OSU and FPS-16 radar #112 for rocket A30.311-7 is given in Table 5. The trajectory comparison is good with a mean deviation of -.187 $\pm$ .093 Km in altitude, -.225 $\pm$ .174 Km in range, .11° $\pm$ .17° in Az, -.01 $\pm$ .05° in El. The range accuracy is not as good as could normally be expected from Tradat but is still accurate enough to meet the mission requirements.

4.1.2 The trajectory data residuals in Table 6 indicate a smooth track with standard deviations of only $\pm$ .06° in Az and $\pm$ .01° in El. The range data was very rough with several dropouts and a standard deviation of $\pm$ .870 Km. The missing data points and the range data for times with an asterisk were replaced by computed values in the editing portion of the computer program. The basis for choosing whether to use the range data or the computed range was made by setting a limit on how large the absolute value of the difference between the data point and the computed point could

TABLE 5

VEHICLE A30.311-7, 2 DEC 75, WSMR, NEW MEXICO, LCH-3 FROM L-479W
DATA ORIGIN LAT 32 25 0.41, LONG 106 19 30.99, ALT 1.233 KM
T-0: 15H 59M 59.761S U.T.; X-EAST, Y-NORTH, Z-ALTITUDE ABOVE LAUNCHER

TRAJECTORY DATA COMPARISON (FPS-16 RADAR #112 - OSU TRACKER)

T-LNCH (SEC)	X (KM)	Y (KM)	Z (KM)	RANGE (KM)	AZ (DEG)	EL (DEG)
20.239	0.012	0.009	-0.035	-0.034	0.29	-0.03
30.239	0.019	0.006	-0.087	-0.086	0.26	-0.02
40.239	0.031	0.011	-0.185	-0.183	0.32	-0.04
50.239	0.013	-0.012	-0.222	-0.221	0.03	-0.00
60.239	0.033	0.031	-0.364	-0.366	0.13	-0.01
70.239	0.037	0.046	-0.262	-0.253	0.26	-0.07
80.239	0.055	0.000	-0.244	-0.243	0.24	-0.02
90.239	0.045	0.024	-0.250	-0.244	0.17	-0.03
100.239	0.093	-0.014	-0.237	-0.239	0.31	-0.02
110.239	0.079	0.102	-0.257	-0.237	0.28	-0.07
120.239	0.115	-0.096	-0.214	-0.232	0.25	0.04
130.239	0.090	-0.033	-0.215	-0.221	0.19	-0.01
140.239	-0.048	-0.347	-0.124	-0.189	-0.24	0.14
150.239	0.024	-0.066	-0.184	-0.194	0.00	0.00
160.239	0.198	-0.009	-0.196	-0.203	0.40	-0.02
170.239	0.135	-0.274	-0.113	-0.182	0.14	0.15
180.239	-0.227	-0.170	-0.158	-0.183	-0.47	0.02
190.239	0.148	-0.028	-0.179	-0.189	0.27	-0.01
200.239	0.075	-0.224	-0.098	-0.163	0.02	0.07
210.239	0.004	-0.027	-0.157	-0.158	0.02	-0.03
220.239	0.026	-0.019	-0.199	-0.195	0.02	0.00
230.239	0.092	-0.082	-0.127	-0.155	0.11	0.02
240.239	0.075	-0.045	-0.140	-0.153	0.08	0.01
250.239	0.075	-0.111	-0.110	-0.154	0.07	0.04
260.239	0.065	-0.055	-0.142	-0.156	0.07	-0.01
270.239	0.065	-0.046	-0.158	-0.164	0.06	-0.02
280.239	0.047	-0.062	-0.148	-0.159	0.05	-0.03
290.239	0.060	-0.072	-0.201	-0.202	0.05	-0.02
300.239	0.098	-0.217	-0.184	-0.297	0.06	-0.05
310.239	0.263	-0.957	-0.564	-1.139	0.06	-0.06
320.239	0.091	-0.151	-0.117	-0.195	0.06	-0.05
330.239	0.083	-0.202	-0.097	-0.228	0.04	-0.04
Mean:	0.060	-0.102	-0.187	-0.225	0.11	-0.01
Standard Deviation:	±0.078	±0.183	±0.093	±0.174	±0.17	±0.05

TABLE 6. A30.311-7 TRAJECTORY DATA RESIDUALS
(UNSMOOTHED-SMOOTHED DATA)

Time (Sec)	Az (Deg)	El (Deg)	Range (Km)
20	.04	-.02	.021
30	.04	.00	-.016
40	.04	.00	-.027
50	.08	.00	.009
60	-.07	.01	.204*
70	-.17	.00	-1.137*
80	-.03	-.01	-2.545*
90	-.06	.00	------
100	-.10	.00	-2.551*
110	.02	.00	------
120	.04	.01	-1.904*
130	-.10	-.01	------
140	.17	.01	------
150	-.24	.01	1.915*
160	.05	.00	------
170	.14	.01	-.398*
180	-.13	-.02	.069*
190	.09	.02	------
200	-.13	.01	------
210	.08	.02	1.750*
220	-.08	-.02	.336*
230	.05	.00	.075*
240	-.03	-.01	------
250	-.06	.01	-.084*
260	.05	-.02	.098*
270	-.04	.02	------
280	.01	.00	-.124*
290	-.03	-.01	.026
300	.00	-.01	-.025
310	.00	.00	-1.030*
320	.00	-.01	-.016
330	-.01	.02	-.016
340	.00	.07	.037
Standard Deviation	±.06	±.01	± .870 (± .80 Excluding *Data)

*Range data at these points and the missing data points are replaced by computed values.

be. The limit was set at 5 Km until T+30, .050 Km from T+20 to T+5^{o}, .001 Km from T+50 to T+280, and .500 Km from T+280 to the end of the flight. If the absolute value of the difference between the data point and the computed point is greater than the limit, the computed point is used and the data point is rejected. The standard deviation of the range data that were not replaced by the editing program is only $\pm$ .080 Km. Replacing bad data points in the editing program is the means by which range data with a standard deviation of $\pm$ .870 Km can compare to within -.225 $\pm$ .174 Km to the radar data.

4.2 Rocket A30.413-5

4.2.1 A comparison of the smoothed OSU trajectory data with radar #114 data for rocket A30.410-5 is given in Table 7. The OSU trajectory data compares favorably to the radar data with a mean deviation of .011 $\pm$ .128 Km in altitude, .062 $\pm$ .258 Km in range, .08^{o} $\pm$ .11^{o} in Az, and .01^{o} $\pm$ .02^{o} in El. The mean deviation through T+270 seconds in the flight is only -.045 $\pm$ .039 Km in altitude and -.054 $\pm$ .044 Km in range.

4.2.2 The trajectory data residuals in Table 8 indicate a smooth track with standard deviations of only $\pm$ .07^{o} in Az and $\pm$ .03^{o} in El. The range data was very rough with a standard deviation of $\pm$ .454 Km. The missing range data points and the range data for times with an asterisk were replaced by computed values in the editing portion of the computer program. The standard deviation of the range data that were not replaced by the editing program is only $\pm$ .054 Km.

4.3 Rocket A30.205-7

4.3.1 Range data was received for only the first 58 seconds of this flight. The range values computed in the editing program are inaccurate during reentry due to the unknown rocket reentry attitude which makes the drag coefficient indeterminate. This is why trajectory data is supplied to only T+280 seconds in Table 9. However, trajectory data is provided during the time scientific data was being taken by the scientific instruments aboard the rocket. On the other flights evaluated from this mission, data was available right after liftoff and during reentry. This makes the editing program very accurate because most of the computed range values may be calculated using only a vacuum trajectory, which is very well defined. The program forces the computed range data to fit the Tradat range

TABLE 7

VEHICLE A30.413-5, 2 DEC 75, WSMR, NEW MEXICO, LCH-4 FROM L-A79W
DATA ORIGIN LAT 32 25 0.41, LONG 106 19 30.99, ALT 1.233 KM
T-0: 00H 35M 00.239S U.T.; X-EAST, Y-NORTH, Z-ALTITUDE ABOVE LAUNCHER

TRAJECTORY DATA COMPARISON (FPS-16 RADAR #114 - OSU TRACKER)

T-LNCH (SEC)	X (KM)	Y (KM)	Z (KM)	RANGE (KM)	AZ (DEG)	EL (DEG)
39.761	0.034	0.014	-0.016	-0.016	0.36	-0.00
49.761	0.011	0.020	-0.014	-0.011	0.13	-0.02
59.761	0.019	0.030	-0.011	-0.008	0.17	-0.02
69.761	0.035	0.009	-0.006	-0.006	0.18	0.00
79.761	0.029	0.032	-0.013	-0.010	0.17	-0.01
89.761	0.037	0.011	-0.008	-0.009	0.15	0.00
99.761	0.082	-0.016	-0.001	-0.008	0.25	0.02
109.761	0.070	0.040	-0.024	-0.021	0.24	-0.01
119.761	0.069	-0.024	-0.009	-0.017	0.16	0.02
129.761	0.075	0.012	-0.026	-0.028	0.19	0.00
139.761	0.056	-0.003	-0.032	-0.036	0.12	0.01
149.761	0.043	-0.066	-0.022	-0.037	0.04	0.03
159.761	0.102	-0.060	-0.031	-0.051	0.16	0.04
169.761	0.054	-0.063	-0.055	-0.071	0.05	0.03
179.761	0.050	-0.044	-0.062	-0.075	0.06	0.02
189.761	0.096	-0.092	-0.057	-0.087	0.10	0.05
199.761	0.005	-0.001	-0.110	-0.106	0.01	-0.01
209.761	0.145	-0.066	-0.077	-0.107	0.18	0.04
219.761	0.017	-0.037	-0.095	-0.103	0.00	0.00
229.761	0.032	-0.056	-0.098	-0.114	0.01	0.01
239.761	0.008	-0.035	-0.118	-0.123	-0.01	-0.01
249.761	0.040	-0.072	-0.098	-0.124	0.02	0.02
259.761	-0.006	-0.058	-0.095	-0.108	-0.03	0.00
269.761	-0.036	-0.054	-0.001	-0.021	-0.06	0.02
279.761	-0.078	0.057	0.146	0.165	-0.06	0.02
289.761	-0.138	0.217	0.291	0.384	-0.06	0.01
299.761	-0.198	0.381	0.349	0.551	-0.06	-0.00
309.761	-0.253	0.561	0.332	0.657	-0.05	-0.02
319.761	-0.293	0.732	0.233	0.820	-0.03	-0.05
329.761	-0.199	0.501	0.068	0.543	-0.02	-0.01
Mean:	--0.003	0.062	0.011	0.082	0.08	0.01
Standard Deviation:	±0.108	±0.206	±0.128	±0.258	± 0.11	± 0.02

TABLE 8. A30.413-5 TRAJECTORY DATA RESIDUALS
(UNSMOOTHED-SMOOTHED DATA)

Time (Sec)	Az (Deg)	El (Deg)	Range (Km)
40	.02	.00	.018
50	-.04	.00	.148*
60	-.33	.00	1.236*
70	.09	-.02	1.023*
80	-.16	.00	-----
90	-.11	.00	-----
100	-.07	-.02	-----
110	.01	-.01	-----
120	-.14	.01	-----
130	-.07	.02	-----
140	-.07	.00	-----
150	-.06	-.01	-----
160	.12	-.01	-----
170	.01	.00	-----
180	-.18	.00	-----
190	-.10	.01	-----
200	.06	-.01	-----
210	.11	-.02	-----
220	-.01	.04	-----
230	-.09	.00	-----
240	-.08	-.01	-----
250	-.03	.00	-----
260	-.01	.00	-----
270	-.01	.03	-----
280	.02	.01	.126
290	-.04	.03	-.104
300	-.06	.06	.027
310	-.01	.01	.430*
320	.00	-.01	-----
330	.01	.14	.630*
Standard Deviation	±.07	±.03	±.454 (± .054 Excluding *Data)

*Range data at these points and the missing data points are replaced by computed values.

TABLE 9

VEHICLE A30.205-7, 2 DEC 75, WSMR, NEW MEXICO, LCH-5 FROM L-479W
DATA ORIGIN LAT 32 25 0.41, LONG 106 19 30.99, ALT 1.233 KM
T-0: 00H 59M 00.499S U.T.; X-EAST, Y-NORTH, Z-ALTITUDE ABOVE LAUNCHER

TRAJECTORY DATA COMPARISON (FPS-16 RADAR #114 - OSU TRACKER)

T-LNCH (SEC)	X (KM)	Y (KM)	Z (KM)	RANGE (KM)	AZ (DEG)	EL (DEG)
29.501	0.024	0.056	0.235	0.240	0.39	-0.03
39.501	0.043	0.083	0.320	0.328	0.43	-0.03
49.501	0.045	0.049	0.287	0.291	0.31	0.00
59.501	0.062	-0.022	0.023	0.018	0.29	0.03
69.501	0.062	0.059	0.208	0.215	0.30	-0.01
79.501	0.062	0.064	0.183	0.189	0.26	-0.01
89.501	0.060	0.071	0.167	0.180	0.21	-0.03
99.501	0.068	0.059	0.157	0.168	0.20	-0.02
109.501	0.082	0.060	0.144	0.145	0.24	0.00
119.501	0.116	0.036	0.138	0.146	0.27	-0.01
129.501	0.108	0.061	0.130	0.126	0.28	0.02
139.501	0.063	0.101	0.119	0.138	0.15	-0.03
149.501	0.016	0.091	0.105	0.216	0.05	-0.19
159.501	-0.004	0.072	0.113	0.074	0.02	0.07
169.501	-0.010	-0.026	0.103	0.114	-0.05	-0.01
179.501	-0.002	0.023	0.087	0.096	0.02	-0.01
189.501	-0.006	0.027	0.080	0.083	-0.01	0.00
199.501	0.014	0.125	0.083	0.094	0.04	-0.01
209.501	-0.036	0.477	0.069	0.205	0.06	-0.16
219.501	-0.055	0.620	0.036	0.437	0.05	-0.45
229.501	-0.027	0.457	0.105	0.106	0.05	0.01
239.501	0.000	0.041	0.040	0.039	-0.01	0.01
249.501	-0.017	0.092	0.028	0.031	0.01	0.00
259.501	-0.023	0.101	-0.000	0.129	-0.01	-0.11
269.501	-0.051	0.126	-0.000	0.013	-0.03	-0.01
279.501	-0.058	0.210	0.022	0.058	-0.03	-0.02
Mean:	0.021	0.120	0.115	0.149	0.13	- 0.04
Standard Deviation:	±0.050	±0.156	±0.083	±0.100	±0.15	± 0.10

data at the beginning and end of the flight to provide accurate range data throughout the flight. Comparison of the OSU trajectory data with the radar data is good as shown in Table 9. The mean deviations were only .115 $\pm$ .083 Km in altitude, .149 $\pm$ .100 Km in range, $.13^{\circ} \pm .15^{\circ}$ in Az, and $-.04 \pm .10^{\circ}$ in El.

4.3.2 The tracking data was excellent with a standard deviation of $\pm .05^{\circ}$ in Az and $\pm .04^{\circ}$ in El as seen in Table 10. Data from T+200 to T+ 226 seconds is missing due to a temporary data recording failure. The standard deviation of $\pm$ 1.885 Km in range from Table 10 is very poor. However, data from only the first 58 seconds of the flight were used and the rest of the range values were computed in the editing program. The range values used to extrapolate the rest of the range data have a standard deviation of only $\pm$ .050 Km.

5.0 SUMMARY AND CONCLUSIONS

A trajectory data evaluation summary of the five rocket flights launched during three missions at two launch sites is given in Table 11. Excellent quality telemetry data and autotrack Az-El data was received from all rockets in all three missions. Range data from the first two missions was excellent and range data from three of the five rockets in the third mission was good enough, with computer editing, to provide good trajectory data support for the mission. In the comparison of the OSU data with the radar data in Table 11, the mean deviation is a measure of the bias or offset of the OSU data from the radar data. A bias in the data is caused by offsets introduced in setting up the tracker or in time-correlating the OSU and radar data. The bias is small, indicating that good set-up and time correlation procedures were used. The N-1 weighted standard deviations presented in the data comparison table mean that there is a one sigma or 68.3% probability that all the data was within the bounds of one standard deviation of the mean. The average of the absolute values of the deviations from all the rocket flights is only .071 $\pm$ .083 Km in altitude, .103 $\pm$ .116 Km in range, $.30^{\circ} \pm .23^{\circ}$ in Az and $.02^{\circ} \pm .06^{\circ}$ in El.

The standard deviations of the trajectory data residuals in Table 11 are a measure of how smooth the OSU data was. The standard deviations mean that there is a one sigma or 68.3% probability that all the OSU data was within the bounds of one standard deviation of the smoothed data. The

TABLE 10. A30.205-7 TRAJECTORY DATA RESIDUALS
(UNSMOOTHED-SMOOTHED DATA)

Time (Sec)	Az (Deg)	El (Deg)	Range (Km)
30	-.03	.00	.102
40	.07	.00	.003
50	.04	.01	.041
60	-.12	.00	----
70	-.05	-.01	----
80	-.12	.01	----
90	.03	.00	----
100	-.08	.01	----
110	-.03	-.01	----
120	-.08	.02	----
130	.08	.00	-2.864*
140	-.15	.00	----
150	-.02	-.19	----
160	.22	-.01	----
170	-.13	.00	----
180	.03	.00	----
190	-.03	.01	----
200	----	----	----
210	----	----	----
220	----	----	----
230	.05	.00	----
240	-.06	.02	-3.367*
250	.01	.01	----
260	-.01	-.12	----
270	-.01	.01	-4.036*
280	.05	-.02	----
Standard Deviation	$\pm$.05	$\pm$.04	$\pm$1.885 ($\pm$ .050 Excluding *Data)

*Range data at these points and the missing data points are replaced by computed values.

TABLE 11. TRAJECTORY DATA EVALUATION SUMMARY

Rocket	Trajectory Data Comparison (Radar-OSU Data) (Mean ± Standard Deviation)				Standard Deviations Of Trajectory Data Residuals (Unsmoothed-Smoothed Data)		
	Altitude (Km)	Range (Km)	Az (Deg)	El (Deg)	Az (Deg)	El (Deg)	Range (Km)
A10.302-3	.032±.039	.034±.030	1.02±.49	.02±.07	± .13	± .05	± .065
A10.304-1	-.012±.072	.045±.017	-1.7±.21	-.04±.05	± .17	± .03	± .028
A30.311-8	No trajectory data comparison. Range receiver failed prior to liftoff.						
A30.311-5	No trajectory data comparison. Range received to only 15 Km.						
A30.311-7	-.187±.083	-.225±.174	.11±.17	-.01±.05	± .06	± .01	± .080*
A30.413.5	.011±.128	.062±.258	.08±.11	.01±.02	± .07	± .03	± .054*
A30.205-7	.115±.083	.149±.100	.13±.15	-.04±.10	± .03	± .04	± .050*
|Average|	.071±.083	.103±.116	.30±.23	.02±.06	± .09	± .03	± .055

*Includes non-computed values only.

average of the standard deviations of the residuals from all five rocket flights indicate that the data was very smooth with average standard deviations of only $\pm .09^{\circ}$ in Az, $\pm .03^{\circ}$ in El, and $\pm$ .055 Km in range. As mentioned previously, there were large portions of the range data from flights in the third mission in which the range data was rough or lost altogether, which necessitated the use of computed range values from the editing computer program.

The data in this report and in References 8 and 9 were compiled over a three year period from many different rocket flights launched from several different launch facilities. This data proves the flexibility of the Tratel/Tradat system to be set up at remote rocket launch facilities to provide trajectory and telemetry support for sounding rocket missions. The problem with the ranging system in the third mission was an operator oversight, and is not a hardware problem. A monitor has been added to avoid the possibility of this problem in the future.

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